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BRIDGE DISASTERS

IN

AMERICA:

THE CAUSE AND THE REMEDY.

BY PROFESSOR GEORGE L. VOSE.

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BRIDGE DISASTERS IN AMERICA.

THE CAUSE AND THE REMEDY.

A few years ago an iron highway bridge at Dixon, Ill., fell, while a crowd was upon it, and killed sixty persons. The briefest inspection of that bridge by any competent engineer would have been sure to condemn it. A few years later the Ashtabula bridge, upon the Lake Shore Railroad, broke down under a passenger train, and killed from 80 to 100 passengers. The report of the committee of the Ohio Legislature appointed to investigate that disaster concluded, first, that the bridge went down under an ordinary load by reason of defects in its original construction ; and, secondly, that the defects in the original construction of the bridge could have been discovered at any time after its erection by careful examination. Hardly had the public recovered from the shock of this terrible disaster when the Tariffville calamity added its list of dead and wounded to the long roll already charged to the ignorance and recklessness which characterizes so much of the management of the public works in this country.

There are many bridges now in use upon our railroads in no way better than those at Ashtabula and Tariffville, and which await only the right combination of circumstances to tumble down. There are, by the laws of chance, just so many persons who are going to be killed on those bridges. There are hundreds of highway bridges now in daily use which are in no way safer than the bridge at Dixon was, and which would certainly be condemned by five minutes of competent and honest inspection. More than that, many of them have already been condemned, as unfit for public use, but yet they are allowed to remain, and invite the disaster which is sure to come. Can nothing be done to prevent this reckless and wicked waste of human life ? Can we not have some system of public control of public works which shall secure the public safety ? The answer to this question will

sponsibility, in case of disaster, upon some person to whom the proper punishment may be applied. If every railway director, or town or county officer, knew that he was held personally accountable for the failure of any bridge in his charge, we should soon have a decided improvement in these structures. If we could show that a certain bridge in a large town had been for a long time, old, rotten, worn-out, and liable at any moment to tumble down, and could show, in addition, that the public officers having charge of such a bridge knew this to be the case, and still allowed the public to pass over it, we can see at once that in case of disaster the blame would be clearly located, and the action for damage would be short and decisive. Once let a town have heavy damages to pay, and let it know at the same time that the town officers are clearly accountable for the loss, and it is possible that it would be willing to adopt some system that should prevent the recurrence of such an outlay.

To see what may be accomplished by an efficient system of public inspection, it is necessary to know something in regard to the structures to be inspected. We have now, in common use in this country, both upon our roads and our railroads, bridges made entirely of iron, bridges of wood and iron combined, and occasionally, though not often now-a-days, a bridge entirely of wood; and these structures are to be seen of a great variety of patterns, of all sizes, and in every stage of preservation. American engineers have always excelled in this branch of their business, being unsurpassed by any other nation. Of late years, so great has been the demand for bridge work that this branch of engineering has become a trade by itself, and we find immense works, fitted up with an endless variety of the most admirably adapted machine tools, devoted exclusively to the making of bridges of wood, iron, steel, or all combined. As in all division of labor the resul of this specialization has been to improve vastly the quality of the product, to lessen the cost, and to increase the demand, until many of our large firms reckon the length of bridging which they have erected by miles instead of feet. As usual, however, in such cases, unprincipled adventurers are not wanting; who, taking advantage of a great demand, do not hesitate to fit up cheap shops, to buy poor material and to flood the market with a class of bridges made with a single object in view, viz., to sell, relying upon the ignorance of public officials for custom. Not a year passes in which some

of these wretched traps do not tumble down, and cause a greater or less loss of life; and at the same time, with uninformed people, throw discredit on the whole modern system of bridge-building. This evil affects particularly highway bridges. The ordinary county commissioner or select-man considers himself amply competent to contract for a bridge of wood or iron, though he may never have given a single day of thought to the matter before his appointment to office. The result is that we see all over the country a great number of highway bridges which have been sold by dishonest builders to ignorant officials and which are on the eve of falling, and await only an extra large crowd of people, a company of soldiers, a procession, or something of the sort to break down.

After a defective bridge falls it is in nearly every case easy to see why it did so. It would be just about as easy to tell in advance that such a bridge would fall if it ever happened to be heavily loaded. Hundreds of highway bridges are to-day standing simply because they never happen to have received the load which is at any time liable to come upon them.

Not many years ago a new highway bridge of iron was to be made over a broad river in one of the largest towns in New England. The county commissioners desired a well-known engineer, especially noted as a bridge-builder, to superintend the work, in order to see that it was properly executed. The engineer, after inspection of the plans, told the commissioners plainly that the design was defective, and would not make a safe bridge; and that unless it was materally changed he would have nothing to do with it. The bridge, however, was a cheap one, and as such commended itself to the commissioners, who proceeded to have it erected according to the original plan; and these same commissioners now point to that bridge, which has not yet fallen, but which is liable to do so at any time, as a complete vindication of their judgment, so called, as opposed to that of the engineer who had spent his life in building bridges.

An impression exists in the minds of many persons that an iron bridge is necessarily a strong bridge. This is a great mistake. There are good iron bridges and there are also very poor ones. A good iron bridge is the best bridge one can buy; but a poor iron bridge is the worst—much worse than a poor wooden one; for when an iron bridge falls it is apt to go all at once, but a wooden one shows signs of failure long before

it actually gives way. Another fallacy which infests some persons is the notion that it is purely a matter of opinion whether a bridge is safe or not. In nine cases out of ten it is not at all a matter of opinion, but a matter of fact, and of arithmetic. The whole question always comes to this: Is the material in this bridge of good quality, is there enough of it, is it properly put together? With given dimensions, and knowing the load to be carried, it is a matter of the very simplest computation to fix the size of each member. We know what one square inch of iron will hold, and we also know total the number of pounds to be sustained; and it is no matter of opinion, but one of simple division, as to how many times one will go into the other.

But, it may be asked, can the precise load which is coming upon any structure be exactly fixed? Are not the circumstances under which bridges are loaded very different? Bridges in different localities are certainly subjected to very different loads, and under very different conditions; nevertheless, the loads to be provided for have been fixed by the best authority for all cases, within narrow enough limits for all practical purposes. Few persons are aware of the weight of a closely packed crowd of people. Mr. Stoney, one of the best authorities, packed 30 persons upon an area of $29\frac{4}{10}$ square feet, and at another time he placed 58 persons upon an area of 57 square feet. In the first case, the result was a load of 149 lbs. per square foot, and in the second case a load of $147\frac{4}{10}$ lbs. per foot "Such cramming," says Mr. Stoney, "could scarcely occur in practice, except in portions of a strongly excited crowd; but I have no doubt that it does occasionally so occur." "In my own practice," he continues, "I adopt 100 lbs. per square foot as the standard working load, distributed uniformly over the whole surface of a public bridge, and 140 lbs. per square foot for certain portions of the structure; such for example as the foot-paths of a bridge crossing a navigable river in a city, which are liable to be severely tried by an excited crowd during a boat-race, or some similar occasion." Tredgold and Rankine estimate the weight of a dense crowd at 120 lbs. per square foot. Mr. Brunel used 100 lbs. in his calculations for the Hungerford Suspension Bridge. Mr. Drewry, an old but excellent authority, observes "that any body of men marching in step at from 3 to $3\frac{1}{2}$ miles an hour will strain a bridge at least as much as double the same weight at rest;" and he adds: "In prudence

not more than one-sixth the number of infantry that would fill a bridge should be permitted to march over it in step." Mr. Roebling says, in speaking of Niagara Falls Railroad Suspension Bridge: "In my opinion, a heavy train, running at a speed of twenty miles an hour, does less injury to the structure than is caused by twenty heavy cattle under full trot. Public processions, marching to the sound of music, or bodies of soldiers keeping regular step, will produce a still more injurious effect."

Evidently a difference should be made in determining the load for London Bridge and the load for a highway bridge upon a New England country road in a thinly settled district. A bridge that is strong enough is just as good and just as safe as one that is ten times stronger, and even better; for in a large bridge, if we make it too strong, we make it at the same time too heavy. The weight of the structure itself has to be sustained, and this part of the load is a perpetual drag on the material. In 1875, the American Society of Civil Engineers, in view of the repeated bridge disasters in this country, appointed a committee to report upon "The Means of Averting Bridge Accidents." We might expect, when a society composed of some hundreds of our best engineers selects an expert committee of half a dozen men, that the best authority would be pretty well represented, and such was eminently the case. It would be impossible to have combined a greater amount of acknowledged talent, both theoretical and practical, with a wider and more valuable experience, than this committee possessed. The first point taken up in the report is the determination of the loads for which both railroad and highway bridges should be proportioned. In regard to highway bridges, a majority of the committee reported that for such structures the standard loads should not be less than as shown in the following table:

Span.	Pounds per Square foot. Class A.	Class B.	Class C.
60 ft. and less	100	100	70
60 to 100 ft	90	75	60
100 to 200 ft	75	60	50
200 to 400 ft	60	50	40

Class A includes city and suburban bridges, and those over large rivers where great concentration of weight is possible; Class B denotes highway bridges in manufacturing districts, having well ballasted roads; and Class C refers to ordinary country road bridges, where travel is less frequent and lighter. A minority of the committee modified the table

above by putting all highway bridges into the first class, and by making the loads larger by a small amount. The whole committee agreed in making the load per square foot less as the span is greater, which is of course correct. It would seem eminently correct to make a difference between a bridge which carries the continuous and heavy traffic of a large city and one which is subjected only to the comparatively light and infrequent traffic of a country road. At the same time it should not be forgotten that in a large part of the United States a bridge may be loaded by ten, twenty or even thirty lbs. per square foot by snow and ice alone, and that the very bridges which from their location we should be apt to make the lightest are those which would be most likely to be neglected, and not relieved from a heavy accumulation of snow. In view of the above, and remembering that a moving load produces a much greater strain upon a bridge than one which is at rest, we may be sure that, as the committee above referred to recommend, the loads should not be less than those given in the table. We can easily see that in special cases they should be more.

There is another point in regard to the loading of a highway bridge which is to be considered. It often happens that a very heavy load is carried over such bridges upon a single truck, thus throwing a heavy and concentrated load upon each point as it passes. Mr. Stoney states that a wagon with a crank shaft of the British ship Hercules, weighing about 45 tons. was refused a passage over Westminster iron bridge, for fear of damage to the structure, and had to be carried over the Waterloo Bridge, which was of stone, and he says that in many cases large boilers, heavy forgings or castings, reach as high as 12 tons upon a single wheel. The report of the American Society of Engineers, above referred to, advises that the floor system be strong enough to carry the following loads upon four wheels: on Class A, 24 tons; Class B, 16 tons, and Class C, 8 tons; though it is stated that these do not include the extraordinary loads sometimes taken over highways. "This provision for local loads," says Mr. Boller, one of the committee, "may seem extreme, but the jar and jolt of heavy springless loads comes directly on all parts of the flooring at successive intervals, and admonishes us that any errors should be on the safe side."

To pass now to railroad bridges, we find here a very heavy load coming upon the structure in a sudden and often very violent manner. Experiment and observation both indicate

that a rapidly-moving load produces an effect equal to double the same load at rest. This effect is seen much more upon short bridges, where the moving load is large in proportion to the weight of the bridge, than upon long spans, where the weight of the bridge itself is considerable. The actual load upon a short bridge is also more per foot than upon a long one, because the locomotive, which is much heavier than an equal length of cars, may cover the whole of a short span, but only a part of a longer one. The largest engines in use upon our railroads weigh from 75,000 to 80,000 lbs. on a wheel-base not over 12 ft. in length, or 2,800 lbs. per foot for the whole length of the engine, and from 20,000 to 24,000 lbs. on a single pair of wheels. The heaviest coal trains will sometimes weigh nearly a ton per lineal foot, the ordinary freight trains from 1,600 to 1,800 lbs., and passenger trains from 1,000 to 1,200 lbs. per foot. Any bridge is liable to be traversed by two heavy freight engines, followed by a load of a ton to the foot, so that if we proportion a bridge for 3,000 lbs. per foot, for the total engine length, and for a ton per foot for the rest of the bridge, bearing in mind that 80,000 lbs. may come upon any 12 ft. of the track, and that any one point may be called upon to sustain 24,000 lbs., and regarding the increase of strain on short spans due to high speeds, we have the following loads for different spans, exclusive of the weight of the bridge :

Span.	Lbs. per foot.	Span.	Lbs. per foot.
12	7,000	50	3,000
15	6,000	100	2,800
20	4,800	200	2,600
25	4,000	300	2,500
30	3,600	400	2,450
40	3,200	500	2,400

The above does not vary essentially from the English practice, and is substantially the same as given by the Committee of the American Society of Civil Engineers.

The load which any bridge will be required to carry being determined, and the general plan and dimensions fixed, the several strains upon the different members follow by a simple process of arithmetic, leaving to be determined the actual dimensions of the various parts ; a matter which depends upon the power of different kinds of material to resist different strains. This brings us to the exceedingly important subject of the nature and strength of materials.

It has been said that we know what one square inch of iron will hold. Like the question of loads, above examined, this

is a matter which has been settled, at any rate within very narrow limits, by the experience of years of both European and American engineers. A bar of the best wrought-iron, one inch square, will not break under a tensile strain of less than 60,000 lbs. Only a small part of this, however, is to be used in practice. A bar or beam may be loaded with a greater weight, applied as a permanent or dead load, than would be safe as a moving or rolling weight. A load may be brought upon any material in an easy and gradual manner so as not to damage it, while the same load could not be suddenly and violently applied without injury. The margin for safety should be greater with a material liable to contain hidden defects than with one which is not so; and it should be greater for any member of a bridge which is subjected to several different kinds of strain than for one which has to resist only a single form of strain. Respect also should be had to the frequency with which any part is subjected to strain from a moving load, as this will manifestly influence its power of endurance. The rule in structures having so important an office to perform as railroad or highway bridges, should be, in all cases, absolute safety under all conditions.

The British Board of Trade fixes the greatest strain that shall come upon the material in a wrought-iron bridge, from the combined weight of the bridge and load, at 5 tons per square inch of the net section of the metal. The French practice allows $3\frac{8}{10}$ tons per square inch of the gross section of the metal, which, considering the amount taken out by rivet holes, is substantially the same as the English allowance. The report of the American Society above referred to recommends 10,000 lbs. per inch as the maximum for wrought-iron in tension in railroad bridges. For highway bridges, which are not subjected to such severe treatment, a unit strain of 15,000 lbs. per square inch is often allowed. A very common clause in a specification is that *The Factor of Safety* shall be four, five or six, as the case may be, meaning by this that the actual load shall not exceed one-fourth, one-fifth, or one-sixth part of the breaking load. It is a little unfortunate that this term, "factor of safety," has found its way into use just as it has, for it by no means indicates what is intended, or what it is supposed to. The true margin for safety is not the difference between the working strain and the breaking strain, but between the working strain and that strain which will in any way unfit the material for use. Now

any material is unfitted for use when it is so far distorted by overstraining that it cannot recover, or, technically speaking, when its elastic limit has been exceeded. The elastic limit of the best grades of iron is just about one-half the breaking weight, or from 25,000 to 30,000 lbs. per square inch; so that the working strain of 10,000 lbs. per inch gives a factor of safety of two and a half or three, instead of six. If the ratio between the elastic limit and the breaking weight, *i. e.*, if the *quality* of the iron was always the same, it might make no great difference how we used our factor; but some iron is hard and brittle, while other iron is soft and ductile. A high breaking strength may be due to the toughness of the iron, or to the hardness of the iron. A soft and ductile iron will stretch more or less before breaking, while a hard iron will often snap short off without warning, and at the same time both may have the same breaking strength. A tough and ductile iron should bend double when cold without showing any signs of fracture, and should stretch 15 per cent. of its length before breaking; but much of the iron used in bridges, although it may hold 50,000 lbs. per inch before failing, will not bend over 90 degrees without cracking, and has an elastic limit as low as 18,000 lbs. It is thus full as important to specify that an iron should have a high elastic limit, as that it should have a high breaking weight. A specification therefore which allowed no material to be strained by more than 10,000 lbs. per inch, and no iron to be used with a less elastic limit than 25,000 lbs., would at the same time agree with the standard requirement both in England and in the United States, and would also secure a good quality of iron.

The writer has before him two documents which illustrate the preceding remarks. The first is the account of the tests of the iron which came from the Tariffville bridge after its failure, and the second is the specification for the bridges upon the Cincinnati Southern Railway. The Tariffville bridge, though nominally a wooden one, like most structures of the kind relied entirely upon iron rods to keep the woodwork together. Though the rods were too small, and seriously defective in manufacture, the bridge ought not to have fallen from that cause. The ultimate strength of the iron was not what it should have been, but yet it was not low enough to explain the disaster; but when we look at the *quality* of the iron we have the cause of the fall. The

rods taken from the bridge show an ultimate tensile strength per square inch of 47,560 lbs., but an elastic limit of only 19,000 lbs., while the strain which was at any time liable to come upon them was 22,000 lbs. per square inch, or 3,000 lbs. more than the elastic limit. The fracture of the tested rods, which it is stated broke with a single blow of the hammer very much in the manner of cast-iron, show a very inferior quality of material. The rods broke in the bridge exactly where we should look for the failure, viz. in the screw, at the end. No ordinary inspection would have detected this weakness. No inspection did detect it; but a proper specification, faithfully carried out, would have prevented the disaster.

Look now at an extract from the specification for bridges upon the Cincinnati Southern Railway :

"All parts of the bridges and trestle-works must be proportioned to sustain the passage of the following rolling load, at a speed of not less than 30 miles an hour, viz.: two locomotives, coupled, each weighing 36 tons on the drivers in a space of 12 feet, the total weight of each engine and tender loaded being 66 tons in a space of 50 feet, and followed by loaded cars weighing 20 tons each in a space of 22 feet. An addition of 25 per cent. will be made to the strains produced by the rolling load considered as static, in all parts which are liable to be thrown suddenly under strain by the passage of a rapidly moving load. A similar addition of 50 per cent. will be made to the strain on suspension links and riveted connections of stringers with floor-beams, and floor-beams with trusses. The iron-work shall be so proportioned that the weight of the structure, together with the above specified rolling load, shall in no part cause a tensile strain of more than 10,000 lbs. per square inch of sectional area. Iron, used under tensile strain, shall be tough, ductile, of uniform quality, and capable of sustaining not less than 50,000 lbs. per square inch of sectional area without fracture, and 25,000 lbs. per square inch without taking a permanent set. The reduction of area at the breaking point shall average 25 per cent., and the elongation 15 per cent. When cold, the iron must bend, without sign of fracture, from 90 to 180 degrees."

A specification like the above, properly carried out, would put an absolute stop to the building of such structures as the Tariffville bridge, and would prevent a very large part of the catastrophies which so often shock the community, and shake the public faith in iron bridges. We have referred above to the factors of safety for wrought-iron under tension only. Similar factors have been determined for other kinds of materials, and for other kinds of strain.

The preceding remarks in regard to the loads for which bridges should be designed, and the safe weight to be put upon the material, are given to show how far the safety of a given bridge is a matter of fact, and how far a matter of opinion. It will be seen that the limits within which we are at liberty to vary are quite narrow ; so that bridge-building may correctly be called an exact science, and there is no excuse for the person who guesses either at the load which a bridge should be designed to bear or at the size of the different members of the structure. Still less can we excuse the man who not only guesses, but who, in order to build cheaply, persistently guess on the wrong side.

We often hear it argued that a bridge must be safe since it has been submitted to a heavy load and did not break down. Such a test means absolutely nothing. It does not even show that the bridge will bear the same load again; much less does it show that it has the proper margin for safety. It simply shows that it did not break down at that time. Every rotten, worn-out and defective bridge that ever fell has been submitted to exactly that test. More than this, it has repeatedly happened that a heavy train has passed over a bridge in apparent safety, while a much lighter one passing directly afterward has gone directly through. In all such cases the structure has been weak and defective, and finally some heavy load passes over and cripples the bridge, so that the next load produces a disaster.

It is very common upon the completion of a bridge to do what is termed testing it. The common practice in England is to load each track with as many engines and tenders as the bridge will hold, and to measure the corresponding deflection. The proof-load varies from one and a half tons per foot on the shorter bridges to one ton per foot upon longer ones; but when the span exceeds 150 ft. in length the load is made somewhat less. In France, the government rules for testing wrought-iron railway bridges are as follows: Bridges under 66 ft. span are loaded with a dead load of one and a half tons per running foot, while bridges over 66 ft. span are loaded with $1\frac{2}{10}$ tons per foot. Besides the above proof, by dead weight, a train composed of two engines, each with its tender weighing at least 60 tons, and wagons each loaded with 12 tons, in sufficient number to cover one span, are run over the bridge at speeds from 12 to 22 miles an hour. A second trial is made with speeds from 25 to 43 miles an hour, with two engines, each with its tender weighing 35

tons, and wagons as in ordinary passenger trains, enough to cover one span. On double-track bridges two trains are made to cross, at first in parallel and then in opposite directions, so that the trains may meet at the centre.

Owing to the lack of any public supervision in the United States, no general method for testing either railroad or highway bridges exists. In some cases it is done, in some cases it is not. Bridges made by our first-class firms, under the direction of engineers, are tested in substantially the same manner as in Europe; but upon many of our smaller railroads, which cannot afford to keep an engineer, and generally in the case of highway bridges, no test is made in many instances for very obvious reasons. In one case of wretchedly cheap and unsafe highway bridge which came recently under the writer's notice, the county commissioners, in order to quiet an impression which had arisen that the bridge was not altogether sound, tested a span 122 ft. long with a load *estimated* to weigh 58,600 lbs., or 480 lbs. per running foot, for a double roadway. The commissioners remarked that they considered this a satisfactory test, as it was not propable that a greater weight than this would ever be applied to the bridge ; and added that the test was made merely to satisfy the public that the bridge was abundantly safe for all practical uses. The public would, no doubt, have been satisfied that the Ashtabula bridge was abundantly safe for all practical uses had it stood on that bridge in the morning and seen a heavy freight train go over it; and yet that very bridge broke down directly afterward under a passenger train. Now, according to the common notion that was a good bridge in the morning, and a very bad bridge, or rather no bridge at all, in the evening. The question for the public is—When did it cease to be a good bridge and begin to be a bad one ? A test like the one referred to above can do no more than illustrate the ignorance or lack of honesty of those who make it, or those who are satisfied with it. Such a test might come within a dozen pounds of breaking the bridge down and no one would be the wiser.

For the test of a bridge to be in any way satisfactory, we must know just what effect such test has had upon the structure. We do not find this out by simply standing near and noting that the bridge did not break down. We must, in the first place, compute the strains which the load throws upon each part of the bridge, and see that no member is

over-strained. We must next measure precisely the amount by which the bridge is depressed under the load, and also how far the work recovers from such depression when the load is removed. A locomotive, when first run on to a bridge, will produce a certain depression—first, by the closing up and stretching of the joints, and secondly by the elongation and compression of the material. If the load is left on for a considerable time the depression will be seen to have slightly increased; but after a longer time it will cease, the bridge having adapted itself to the new conditions impresssd upon it. When the load is removed, the work will recover its first position, less a small amount, termed the permanent *set.* So long as the load is kept within the proper limits this permanent set is not increased by any number of subsequent applications of the force that produced it, and no harm is done; but when the load is so great that each application of the force increases the set, we have passed the elastic limit, and failure is only a question of time. It is important therefore to put the load on a second time, and to be sure that the bridge does not go below the point reached at first. In some cases a second application of the load has appeared to increase the permanent depression ; but it is quite likely that in such instances the time during which the load was applied at first was too short for the full effect to show itself. Ample time, too, should be allowed for the material to recover after the removal of the load. Mr. Stoney states that the set of wrought-iron relaxes to a considerable extent, even after the lapse of several days after the load has been removed.

In view of the preceding, what shall we say of a bridge company that deliberately builds a bridge in the middle of a large town, where it will be subjected to heavy teaming, and, owing to its peculiar location, to heavy crowds, and warrants to the town that it shall hold a ton to the running foot, when the very simplest computation shows beyond any chance of dispute that such a load will strain the iron to 40,000 lbs. per square inch ? We are to say either that such a company is so ignorant that it does not know the difference between a good bridge and a bad one, or else so wicked as to knowingly subject the public to a wretchedly unsafe bridge.

The case referred to is not an imaginary one, but exists to-day in the main street of a large New England town. The joints in that bridge which will safely hold but 20,000 lbs.

will be required to hold 60,000 lbs. under a load of one ton per lineal foot, which the builders have warranted the bridge to carry safely. The case was so bad that after a lengthy controversy the town officers called a commission, and had a thorough expert examination of the bridge. The commission reported as follows: first, "The bridge in its present condition might carry with tolerable safety the ordinary daily traffic to which it is now subjected;" second, "If a span of this bridge should at any time be subjected to a closely packed mass of people on the draw-bridge, or a loosely packed crowd on top of a heavy accumulation of ice or snow, it would in either of these cases be in imminent danger of falling, and would be so over-strained as to unfit it for even moderate service;" third, "If the span should have a heavy accumulation of ice or snow on it, and in that condition be subjected to a close-packed mass of people, it would certainly fall." The commission further reported that the bridge at one place had a factor of safety of only $1 \frac{15}{100}$; and as this factor refers to the breaking weight, and not to the elastic limit, the real factor would be about *one-half;* or, in other words, half the load which is at any time liable to come upon the bridge will strain it beyond the elastic limit, while $1 \frac{15}{100}$ times the load will break it down.

Notwithstanding all this, and in the face of this report, the president of the bridge company, came out with the statement in the papers that he "pronounced the bridge perfectly safe." Thus we actually have the president of a bridge company in this country stating plainly that a factor of $1\frac{15}{100}$, referred to the breaking weight, makes a bridge "perfectly safe;" for he very wisely made not the slightest attempt to disprove any of the conclusions of the commission; and this company has built hundreds of highway bridges all over the United States, and is building them to-day where-ever it can find town or county officers ignorant enough or wicked enough to buy them.

It might be supposed that under the above condemnation the authorities controlling the bridge would have taken some steps to prevent the coming disaster. They did, however, nothing of the kind; but allowed the public to travel over it for more than a year, at the most fearful risk, until public indignation became so strong that a special town-meeting was called, and a committee appointed to remove the old bridge and to build a new one. This is only one of

many cases just as bad which happen to be within the writer's knowledge.

The Ashtabula bridge, it is stated in the Ohio report above referred to, had factors—we can hardly call them factors of safety—in some parts as low as 1 $\frac{6}{10}$ and 1 $\frac{2}{10}$, such factors referring to breaking weight; and even these factors were obtained by assuming the load as at rest, and making no allowance for the jar and shock from a railway train in motion. Well may the commissioners say as they do at the end of their report: "The bridge was liable to go down at any time during the last ten or eleven years, under the loads that might at any time be brought upon it in the ordinary course of the company's business, and it is most remarkable that it did not sooner occur."

One point always brought forth when an iron bridge breaks down, is the supposed deterioration of iron under repeated straining, and we are gravely told that after a while all iron loses its fibre and becomes crystalline. This is one of the "mysteries" which some persons conjure up at tolerably regular intervals to cover their ignorance. It is perfectly well known by engineers the world over, that with good iron properly used, nothing of the kind ever takes place. This matter used to be a favorite bone of contention among engineers, but it has long since been laid upon the shelf. No engineer at the present day ever thinks of it. We have only to allow the proper margin for safety, as our first-class builders all do, and this antiquated objection at once vanishes. The examples of the long duration of iron in large bridges are numerous and conclusive. The Niagara Falls railroad suspension bridge was carefully inspected after 22 years of continued use under frequent and heavy trains, and not only was it impossible to detect by the severest tests any deterioration of the wire in the cables, but a piece of it being thrown upon the floor curled up showing the old "kink" which the iron had when made. The Menai suspension bridge, in which 1,000 tons of iron have hung suspended across an opening of nearly 600 ft. for 55 years, shows no depreciation that the most rigid inspection could detect. Iron rods recently taken from an old wooden bridge after 60 years of use have been carefully tested, and found to have lost nothing either of the original breaking strength or of the original elasticity.

The question is frequently asked, does not extreme cold weaken iron bridges. To this it may be replied that no iron

bridge made by a reliable company has ever shown the slightest indication of any thing of the kind, though they have been used for many years in Russia, Norway, Sweden and Canada; and nothing that we know in regard to iron gives us any reason to suppose that anything of the kind ever will happen. But here again the whole question turns upon the quality of the iron. Iron containing phosphorus is "cold short," or brittle, when cold, and will break quicker under repeated and sudden shocks in cold weather than when it is warm. It is a well-known fact that a good many more rails break upon New England railroads in winter than in summer. In Scandinavia this is not the case, simply because the iron used in that country is of the best quality. In the words of Mr. Sandberg, the great Swedish authority on iron, "Rails made of suitable iron with a proper section will not break in winter. In Scandinavia, with a climate more severe than in America, no accident has occurred from broken rails. But a very small part of the rails shipped to America will stand the proper tests. Iron highly impregnated with phosphorus, or cold-short iron, is utterly unfit for railroad purposes in countries subject to great and sudden changes of temperature." An immense number of experiments upon all sorts of iron show conclusively that cold has no effect whatever upon the strength of good iron. The securing such iron is a matter to which the utmost attention is paid by our first-class bridge-building firms; but it is a matter to which no attention is paid by the builders of cheap bridges. We might suppose that a person in putting an in sufficient amount of iron into a bridge would be careful to get the best quality; but exactly the reverse seems to be the case; on the ground, perhaps, that the less of a bad thing we have the better.

Many railroad companies in building wooden bridges take no pains to get iron rods which are suitable for such work, but purchase what is easiest to be had in the market, and in many cases never find that the iron was bad until a bridge tumbles down. There are, without the slightest question, hundreds of bridges now in use in this country, which as far as mere proportions and dimensions go would appear to be entirely safe, but which on account of the quality of the iron with which they are made are entirely unsafe; and there always will be as long as railway presidents, superintendents or roadmasters buy iron which they know nothing about, to put into bridges. When a bridge is finished the

ordinary examinations never detect the quality of the iron: so that the wise remarks of many inspectors, or the opinions of the ordinary hands employed on a road, as to the exact condition of a bridge are of little or no value.

We often hear iron bridges condemned, while wooden ones, so called, are supposed to be free from defects. It does not seem to occur to persons holding such ideas that wooden bridges rely just as much upon the strength of the iron rods that tie the timbers together as upon the timber, and that the effect of cold is if anything worse upon the iron rods in a wooden bridge than upon the rods in an iron bridge, as in the latter all parts expand and contract together, while in the former the rods and the timbers are affected very differently. From this cause it often happens that the rods in wooden bridges in the northern part of the United States, where the temperatnre varies from 30 degrees below zero to 90 above, by contracting bring upon themselves a strain enormously greater than they were ever intended to bear. As a matter of fact, where one iron bridge fails, a dozen wooden ones do the same thing. One very decided advantage which an iron bridge has over a wooden one is that we can make sure of good iron in the beginning, and that we can also be sure that it does not decay; while, however good our timber may be in the beginning, we can never be entirely sure of its condition afterward. There are wooden bridges now standing in this country all the way from 50 to 70 years old, which are apparently as good as ever, while there are others not 10 years old which are so rotten as to be unfit for use. Especially difficult is it to detect that most insidious foe to timber, dry rot, which, lurking in the most inaccessible places, often eludes the most faithful examination. It will not do to assume that, because no defects are very evident in a wooden bridge, therefore it has none. When a wooden bridge, originally made of only fair material, has been in use under railroad trains for 25 or 30 years, and in a position where timber would naturally decay, we are bound to suspect that bridge. To assume such a bridge to be all right until we can prove it to be all wrong, is not safe. To assume a bridge to be all wrong until we can prove it to be all right is a safe method, though not a popular one. Any person who has had occasion to remove old wooden bridges will recall how often they look very much worse than was anticipated.

There is one defect in railway bridges which has often led to the most fearful disasters, and which, without the slightest question, can be almost entirely, if not entirely, removed, and at a moderate cost. At least half the most disastrous failures of railroad bridges in the United States have been due to a defective system of flooring. With a very large number of our bridges the failure of a rail, the breaking of an axle, or anything which shall throw the train from the track, is almost sure to be followed by the breaking down of the bridge. This was without question the cause of the recent disaster at St. Charles. A truck near the middle of a train of 17 loaded stock cars broke down, so that the car left the track, cut through the floor, destroyed the lateral bracing and dragged the trusses down on top of it. With the exception of the floor this was one of the finest bridges in the United States, and was built by one of our very best bridge-building firms. This was one of four railway bridges destroyed from the same cause, derailment, in the single month of November last. The report of the American Society of Civil Engineers referred to on a preceding page observes in regard to this matter:

"In most of our railroad bridges the floor system is the weak point. The cross-ties are short, the stringers are proportioned for a train *on* and not *off* the rails, and the guard timbers are too low and insufficiently bolted. A derailed engine on such a floor as this plunges off the ends of the cross-ties, into the open space between the stringers and the chords, and generally wrecks the bridge. To obviate this, all cross-ties should extend from truss to truss, and be placed so close to each other that, if supported at the proper intervals it will be impossible for a derailed engine to cut through them; and the stringers should be so spaced as to give them this support. Next, the guard timbers should not be less than 9x10 inches, and should be strongly bolted or spiked to each alternate cross-tie; and lastly, the clear width between the trusses should be so great that the wheels of a derailed train will be arrested by the guard rail before the side of the widest car can strike the truss."

Another point, which has often been neglected is making sufficient provision to resist the force of the wind. A tornado such as is not uncommon in this country, will exert a force of 40 lbs. per square foot, which upon the side of a wooden bridge, say of 200 ft. span and 25 ft. high, and boarded up as many bridges are, would amount to a lateral thrust of no less than 100 tons; and this weight would be applied in the worst possible manner, *i. e.*, in a series of shocks. There have been many cases in this country where bridges have

been blown down, and a case recently came to the writer's notice where an iron railroad bridge of 180 ft. span and 30 ft. high, of the Whipple pattern, and presenting apparently almost no surface to the wind, was blown so much out of line that the track had to be moved. No doubt the recent terrible disaster at the Frith of Tay was due to this cause.

At the time of the Tariffville catastrophe it was gravely stated at the coroner's inquest, and by railroad officers who claimed to know about such things, that the disaster was caused by the tremendous weight of two locomotives which were coupled together, and it was stated that one engine would have passed in safety; and directly afterward the superintendent of a prominent railroad in New England issued an order forbidding two engines connected to pass over any iron bridges. It is all very well for a company to issue such an order so far as it may give the public to understand that it is determined to use every precaution against disaster, but such an order may have the effect of creating a distrust which really ought not to exist. If a rail road bridge is not entirely safe for two engines, it is certainly entirely unsafe for one engine and the train following, the only saving in weight by taking off one engine being the difference between the weight of that engine and the weight of the cars that would occupy the same room. For example, a bridge of 200 ft. span will weigh 1,500 lbs. per lineal foot. An engine with its tender will weigh 60 tons in a length of 50 ft., and a loaded freight train may easily weigh two-thirds of a ton per lineal foot. The total weight of the span, with two engines and the rest of the bridge covered with loaded freight cars, would therefore be 320 tons. If we take off one engine and fill its place with cars, we take off 60 tons and put in its place 33 tons; *i. e.*, we remove 27 tons, or just about *one-twelfth* of the working load. Taking off a large part of the working load, however, is taking off a very small part of the breaking load. With a factor of safety of six, for example, taking off one-twelfth of the working load is taking off less than *one-seventieth* of the breaking load. An order, therefore, like that above can only be of use when the working load and the breaking load are so near alike that the actual load is a dangerous one; that is, when the bridge is unfit for any traffic whatever; so that if such an order was really needed, it would in itself be in the eyes of an engineer a condemnation of the bridge.

Having seen something of the structures which require in-

specting, let us now see what kind of inspection we have in this country, and the results of it, and let us also see the inspection which we might have and the results that might be produced. Looking first at railroad bridges, it might be supposed that no one could be so much interested in keeping such structures in good order as the companies which own those bridges, and which have the bills to pay in case of disaster. This is, of course, so; but in spite of the fact the Ashtabula bridge did break down on one of the best-managed lines in the country, and cost the company something over half a million dollars. No railroad bridge ever broke down which the owners were not interested in keeping safe; but there is always a desire to put off incurring large expenses until the last moment, and thus bridges are very often let go too long. A short time since the superintendent of a large railroad stated plainly before a legislative committee that many of the smaller roads were not safe to run over, but that such roads were having a hard time, and could not afford to keep their track and bridges in a safe condition. During the past ten years over 100 railroad bridges in the United States have broken down. These bridges were all kept under such inspection as the railroad companies owning them considered sufficient, or such as they could afford; but either the supervision was defective, or the companies knowingly continued the use of unsafe bridges, and this fault has by no means been confined to the smaller and poorer roads. It would seem, therefore, that inspection by the companies themselves has not been sufficient. It certainly has not been enough to prevent 100 disasters in ten years. It is the custom in several of the United States to maintain what is termed a railroad commission. The original intention seems to have been for these commissions to keep the railroads under some kind of inspection, and in some way to assist in settling the various disputes which might arise between different railroad companies, and between railroad companies and the public. Upon the latter points we may very quickly dismiss the question as to the value of such organizations. It is hardly to be expected that powerful railway companies, with shrewd and able men at their heads, will submit nice legal or commercial questions to a fluctuating board of political appointees. Even in Massachusetts, where the railroad commission appears in its best aspect, it is admitted by its

strongest advocates, after ten years of existence, to be but an experiment which cannot yet be pronounced an assured success. With regard to the value of the inspection of bridges, by any such commissions, we should hardly suppose that three men, in many cases entirely unacquainted with mechanical matters, could by riding over a railroad once or twice a year, occasionally getting out to examine the paint on the outside of the boards which conceal a truss from view, judge very correctly of the elastic limit of the iron which they have never seen, and of which they do not even know the existence.

For ample proof of the utter inefficiency of the present system of public inspection, we have only to compare the reports of the railroad commissioners in almost any state with the actual condition of the structures described. The writer has done this to a certain extent in several states, in which he has now a personal knowledge of many bridges. In one state the last annual report covers a whole railroad with the remark, "All of the bridges on this line are in excellent order;" and yet there were at that very time, and are now, on that road, several large wooden bridges with a factor of safety, referred to the breaking weight, of not over two, under a fair load, assuming the iron rods to be of the very best material, a point upon which there is no evidence whatever. In another state an iron bridge is in use under heavy trains which has a factor of only two and a half, and yet the state report pronounces it an excellent structure and a credit to the railroad company (which furnished the commission with free passes). In a third case the commissioners stated plainly to the writer that a certain bridge was undoubtedly weak, but that it was on a line over which very few passengers traveled. A man's neck, however, is as valuable, as far as the owner is concerned, on one road as on another. In one instance, in answer to the enquiry how the commissioners had been able to report upon a large wooden bridge, which was so covered in as to be entirely hidden, it was replied: "Well, we went over that bridge in the night; but the road-master told us that the bridge was in good order." No wonder that railroad officials have an undisguised contempt for the state inspection. The commissioners of three of the most important states in the Union did not hesitate to admit to the writer a year ago that no one of them had ever computed the strains on a single bridge in the state, but supposed that to be the business of the builder; and one officer, in reply to a

question in regard to some covered wooden bridges, which had been in use 27 years, stated that the frames of the bridges had always been hidden by the boarding, and remarked that if the railroad company did not regard it necessary to "tear the bridge to pieces" in order to inspect it, the commissioners certainly did not.

Evidently such inspection as this is of no value. It is exactly this utterly incompetent and dishonest inspection, this guessing that a bridge will stand until it falls, that lies at the bottom of half the disasters in the country. It is under exactly such inspection that those wretched traps, the Ashtabula and Tariffville bridges, fell and killed over 100 people.

While in a few states the inspection is not quite so bad as that above referred to, as a general thing it is no better; and and we have no right to expect anything better under the present system. The state inspection which we have had throughout this country, has not prevented the failure of 100 bridges during the past ten years.

With regard to highway bridges, we are, if possible, even worse off; for in the case of such structures neither the owners nor the state make any pretence at inspection. It is impossible to say how many highway bridges have broken down during the past ten years, but it is estimated by bridge-builders that the number cannot be less than 200. This is about one a year for every two states, and is no doubt far within the truth. It is quite as important that highway bridges should be built and kept under some kind of public control as that railroad bridges should; perhaps even more so, as towns and counties are much more likely to be imposed upon by dishonest bridge-builders than railway companies are.

A few years ago a town in which the writer lived wanted a new bridge. The selectmen knew nothing at all in regard to bridges or bridge-builders. Instead of getting advice from some one conversant with such matters, they allowed themselves to be imposed upon by the agent of a concern they knew nothing about. The bridge company was allowed to make its own specification and to draw up the contract. The specification and contract were such as would not for one moment be looked at by an engineer. If the object had been to prepare a document which should mean absolutely nothing, it could not have been done more effectually. The company did not even carry out is own absurd specification, but violated it outrageously. It charged an exorbitant

price, and gave the town a bridge which a committee of experts reported had a factor of safety of 1 15-100ths, and would certainly fall under a heavy load. Add to this the fact that the county commissioners in the next town, in full knowledge of all that had been done above, deliberately proceeded to employ the same company to make another bridge of exactly the same kind, and we can see pretty clearly the value of the present system, if it can be called such, of highway bridge work in this country; and the above is a perfectly fair specimen of the general practice in the United States.

If we knew positively that in just six months a terrible disaster would occur under the present system of railroad inspection. and knew also that by a better system such disaster would certainly be prevented, it is possible that a change would be made. We know that a proper method of building and of inspecting bridges would certainly have prevented the disasters at Ashtabula, Tariffville and Dixon. We know that the inspection which those bridges received did not prevent three of the most fearful disasters the country has ever seen. Admitting, now, that structures so important to the public safety as bridges both upon roads and railroads ought to be kept under rigid inspection and control, and that no system at present existing has been able to prevent the most fearful catastrophes, what shall we do? Directly after the Ashtabula disaster the Ohio legislative committee appointed to investigate that affair presented a bill, evidently suggested by the report of the American Society of Engineers, "To secure greater safety for public travel over bridges," in which was plainly specified the loads for which all bridges should be proportioned, the maximum strains to which iron should be subjected, and a method for inspecting the plans of all bridges before building and the bridges themselves during and after construction. The Governor, with the consent of the Senate, was to appoint the inspector for a term of five years, at a salary not exceeding $3,000 a year; such inspector to pass a satisfactory examination before a Committee of the American Society of Engineers, themselves practical experts in bridge construction, and he was also to take a suitable oath for the faithful performance of his duty. This bill never became a law. An appropriation was made for a short time to pay for certain examinations, and there the matter stopped.

The Committee of the American Society of Engineers

were not agreed upon this matter. Messrs. James B. Eads and Charles Shaler Smith suggested the appointment in each state of an expert, to whom all plans should be submitted, and by whom all work should be inspected, such expert to have been examined and approved by the American Society of Engineers. This inspector was also to visit the scene of every accident, so called, and to ascertain as far as possible the cause. Messrs. Thomas C. Clarke and Julius W. Adams believed that in the present state of public opinion, the above method would be impracticable, and feared that if inspectors were appointed, it would be by political influence, and that the result would be worse than at present, as the inspectors would be inefficient, and yet to a great extent would relieve the owners of bad bridges from legal responsibility. They held that the best that could be done would be to provide means in case of a disaster to fix plainly the responsibility; and recommended, first, that the standard for strength fixed by the Society, and referred to on a preceding page, should be the legal standard, and in case it should be found that any bridge was of less strength than this, it should be taken as *prima facie* evidence of neglect on the part of the owners; second, that no bridge should be opened to the public until a plan giving all dimensions, strains, and loads, sworn to by the designers and makers, and attested by the corporation having control of it had been deposited with the American Society, and further, that the principal pieces of iron in the bridge should be stamped with the name of the maker, place of manufacture and date. Messrs. Alfred P. Boller and Charles Macdonald looked rather toward effecting the desired result, by so directing public sentiment, by keeping the correct standard for bridges before it, that it would eventually compel the passage of the necessary laws.

Whether it is possible in this country to make an appointment dependent purely upon honesty and capacity, and free from political influence, may well be doubted. The examination before the expert committee of the American Society would seem to be an excellent idea, and would be pretty sure to keep the number of applicants down to a tolerably low figure. In case such a plan was found feasible, let the state appoint a single person, say upon the nomination of the Society of Engineers, as inspector of roads and bridges, or state engineer. Pay him for his whole time, and let him give his whole time to the work, for he will need to do it. Such person should have in his possession a complete set of

plans of every bridge of importance in the state, with all the computations of its strength, and as complete a history of each structure from its commencement as can possibly be made up, all this to be supplemented by at least two annual examinations. If from such records we find that a bridge was made of ordinary green timber, 25 years ago, and that it has been getting rotten ever since, that it has rods of common merchant-iron that were bought by the president or superintendent of a railroad from an unknown firm, we had better pull it down before it falls. If from such records we find an iron bridge, built 25 years since by an unknown company, with iron at best of doubtful quality, and having a factor of three or four for the rolling-stock and speeds of twenty years ago, instead of a factor of six for the rolling-stock and speeds of to-day, we had better remove that bridge before it removes itself.

Such a record would be the property of the state, always accessible to any one, and would be handed down, so that the knowledge of one person would not expire with his term of office. No bridge should be erected in any state, without first submitting the plans to the inspector, and receiving his approval, and depositing with him a complete set of the plans and computations for the work. By this approval, is not meant that the inspector is merely to give a favorable opinion as to the plan, but that he is to find, as a matter of fact, whether the proposed dimensions and proportions are such as will make a safe bridge; and just what a safe bridge is can be plainly defined by law, as it is in Europe, and as it has been proposed by the American Society of Civil Engineers. For example, if the law says that an iron railway bridge of 100 feet span shall be proportioned to carry a load of 3,000 lbs. per lineal foot, besides its own weight; and that with such a load no part shall be strained by more than 10,000 lbs. per inch; all the inspector has to do is to go over the figures and see if the given dimensions on the plan are such as will enable the bridge to carry the load without exceeding the specified strains. When the work is erected, the inspection must know that the plan has been exactly carried out, and good evidence of the quality of the material used should also be given. Such inspection as this would at once prevent the erection of bridges like those at Ashtabula and Tariffville, and would save the public from such traps as that at Dixon, and the one above referred to as having a factor of safety of $1\frac{15}{100}$

To conclude: Thirty bridges, on an average, break down in the United States every year. No system of inspection or control at present existing has been able to detect in advance the defects in these structures, or to prevent the disasters. A system, practicable, simple and inexpensive, can be had, which if properly carried out will insure in nearly all cases, if not all, the public safety. It lies with the public to say whether or not it will have such a system.